Energy-energy correlator (EEC) measurement in p+p collisions at 5 TeV

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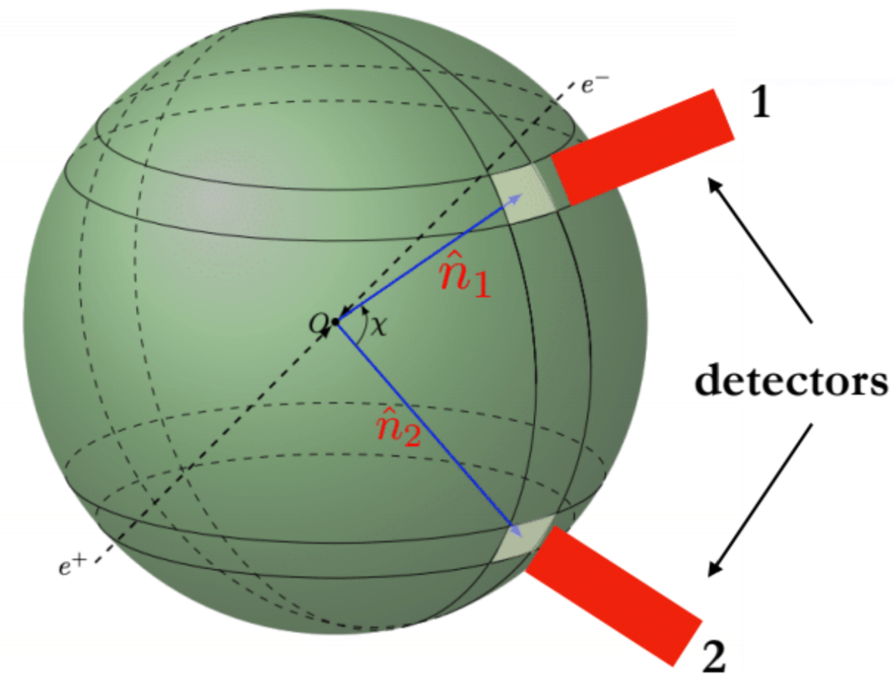
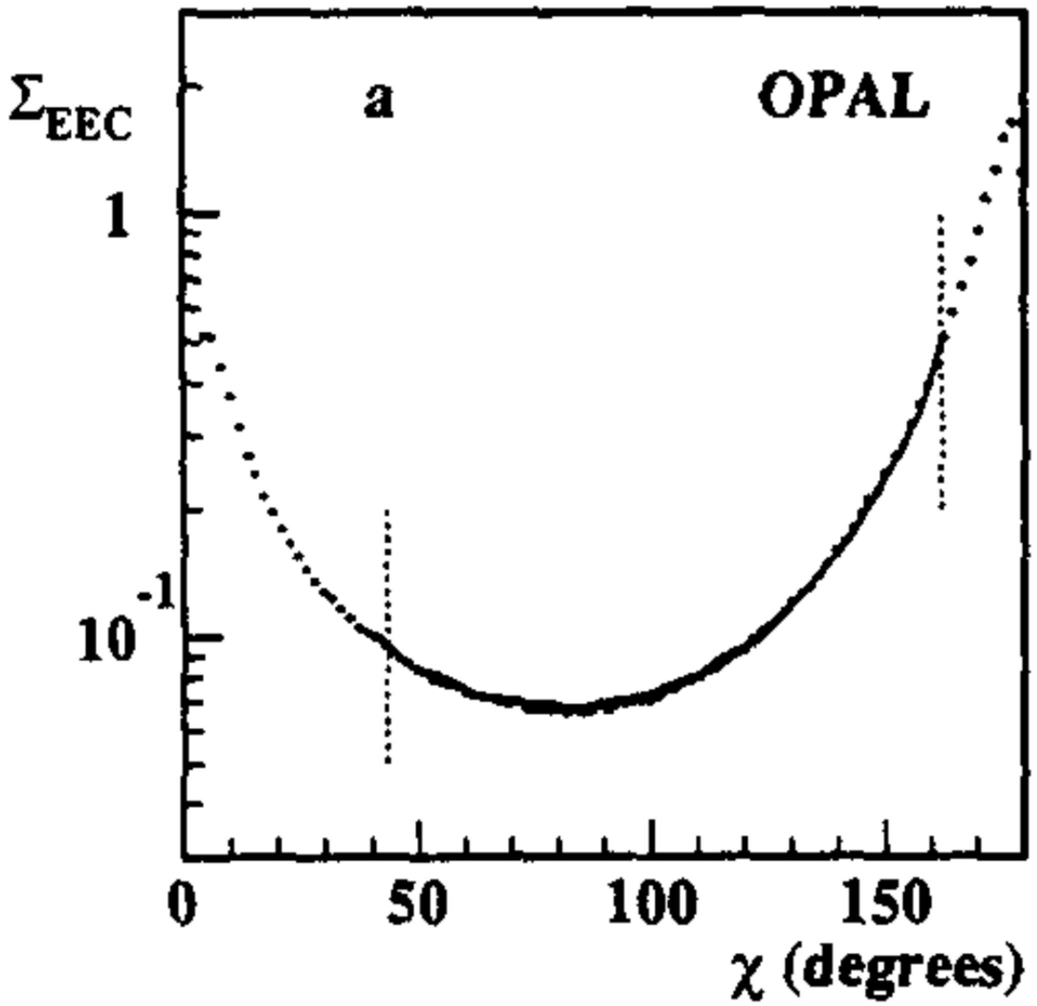
Energy-energy correlator (EEC) at e^+e^- collider

- IRC safe, energy weighted cross section
  - Has been predicted and measured in e^+e^- collider
  - Used to constrain α_s



Phys. Lett. B 276, 547–564



$$\Sigma_{\mathrm{EEC}}(\chi) = \frac{1}{\Delta\chi \cdot N} \sum_{N} \int_{\chi-\frac{1}{2}\Delta\chi}^{\chi+\frac{1}{2}\Delta\chi} \sum_{i,j} \frac{E_i E_j}{E_{\mathrm{vis}}^2} \cdot \delta(\chi' - \chi_{ij})\, \mathrm{d}\chi' , \qquad (4)$$

where E_i and E_j are the energies of particles i and j, E_{vis} is the sum over the energies of all particles in the event, $\Delta\chi$ is the angular bin width and N is the total number of events. The normalization ensures that the integral of $\Sigma_{\mathrm{EEC}}(\chi)$ from $\chi = 0°$ to $180°$ is unity.

EEC as jet substructure in the collinear limit

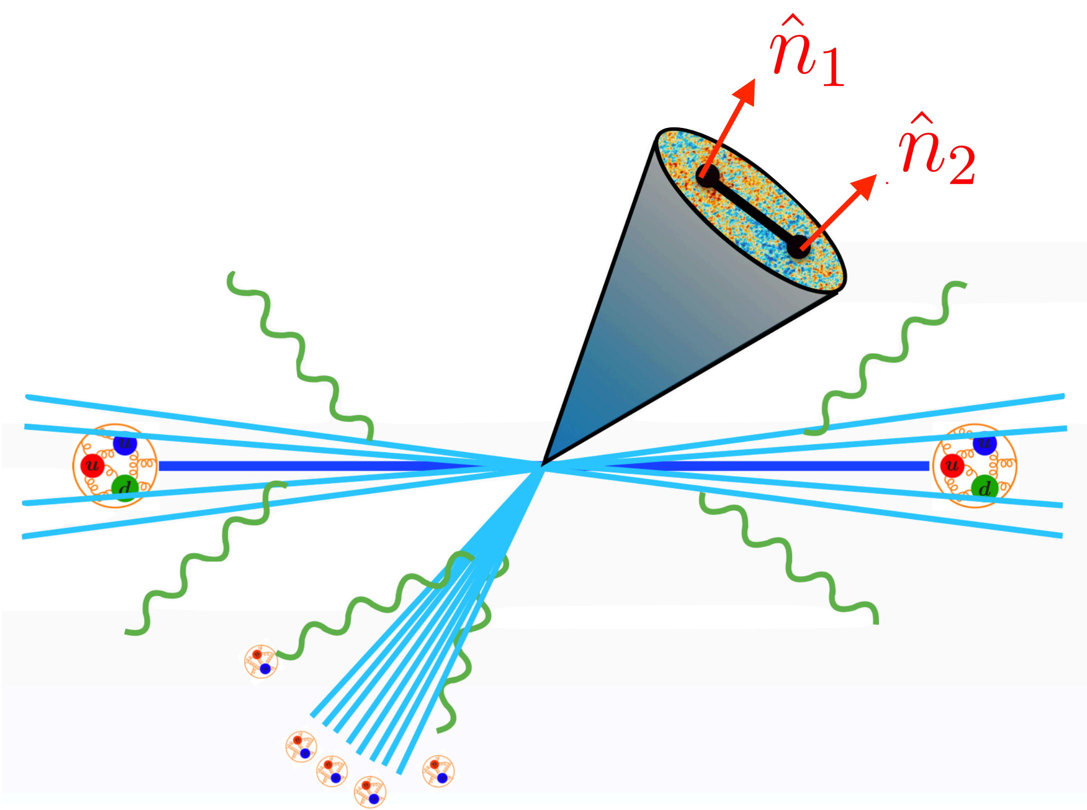
Energy weight

$$\frac{d\sigma_{\mathrm{EEC}}}{dR_{\mathrm{L}}} = \sum_{i,j} \int d\sigma(R'_{\mathrm{L}}) \frac{p_{\mathrm{T},i}\, p_{\mathrm{T},j}}{p^2_{\mathrm{T,jet}}} \delta(R'_{\mathrm{L}} - R_{\mathrm{L},ij})$$

Angular distance

$$R_{\mathrm{L}} = \sqrt{\Delta\varphi^2_{ij} + \Delta\eta^2_{ij}}$$

Step 1. Jet clustering



Step 2. Count number of weighted track pairs as function of R_{L}

$$\frac{p_{\mathrm{T},1}\, p_{\mathrm{T},2}}{p^2_{\mathrm{T,jet}}}$$

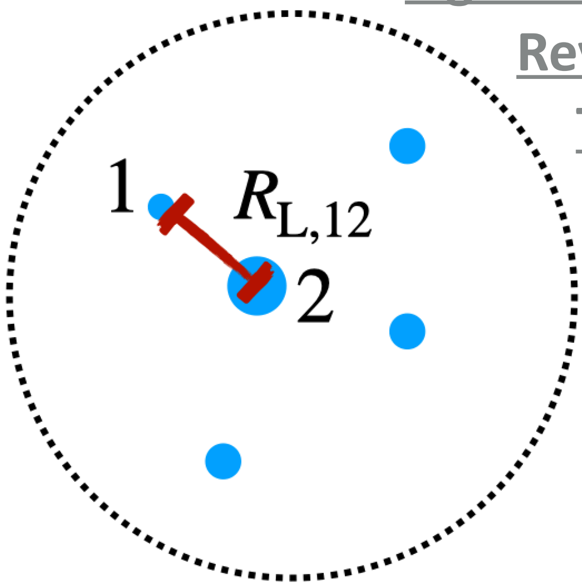
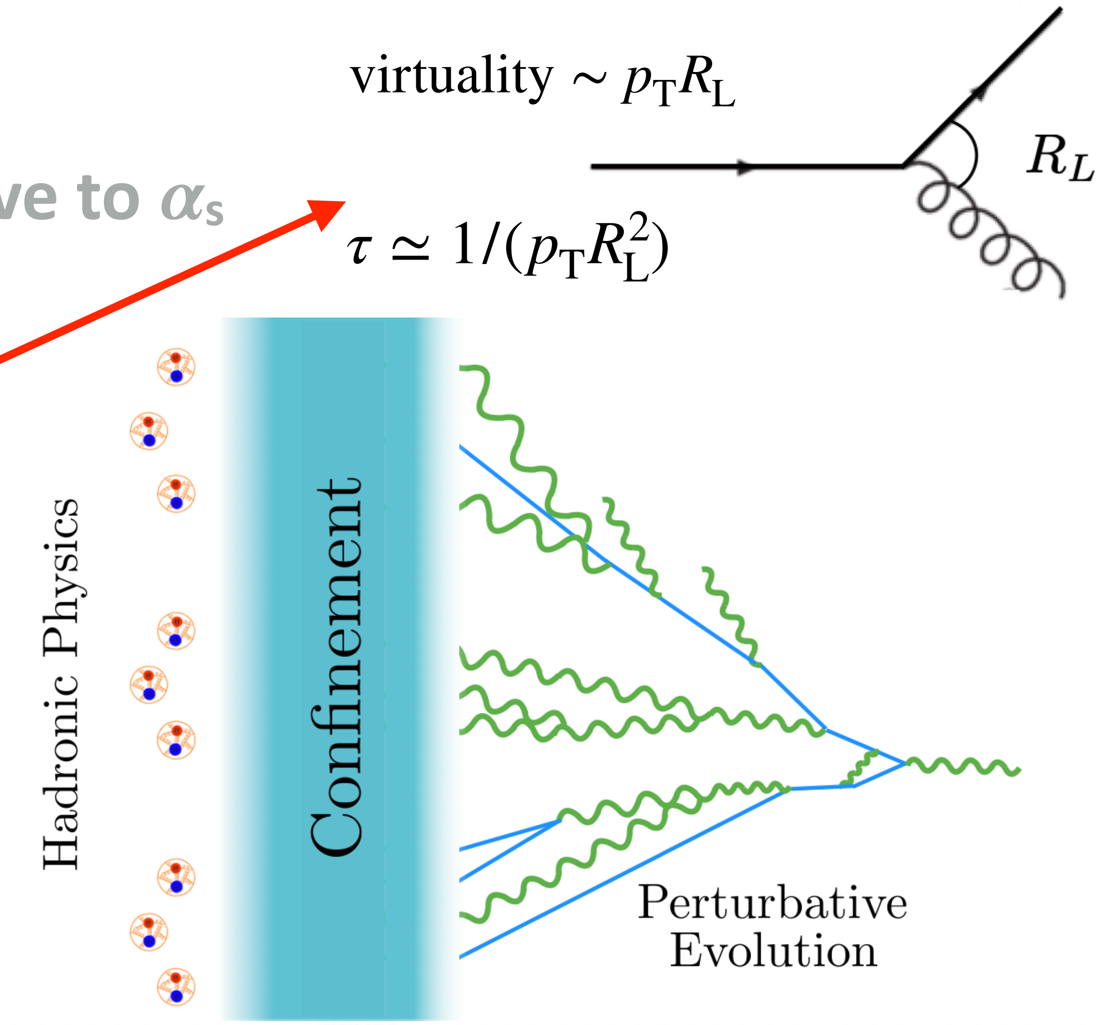


Figure credit: Rey Cruz Torres

- Reduced sensitivity to the soft radiation (power suppressed by energy weighting)
  - No need of grooming
  - Raising the power of the energy weight can further suppress the soft component → reduce contribution from underlying event (UE)

Why study this observable?

- Perturbative calculation in QCD available
- Scaling behavior of N-point correlator sensitive to α_s
- Sensitive probe of initiating parton (i.e. quark vs. gluon)
- **Probing fixed scale with fixed R_L**

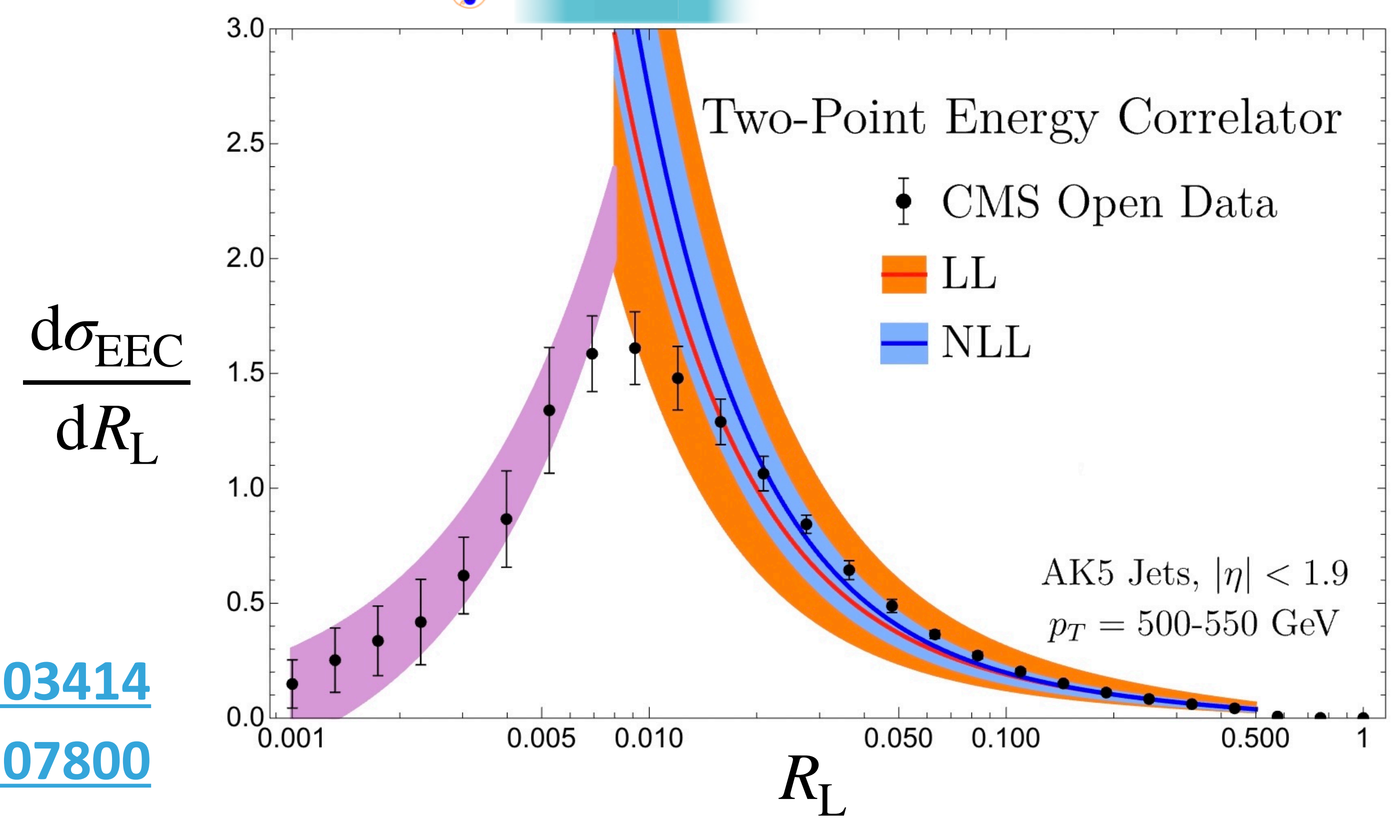


Clear separation of the perturbative region (larger R_L) and non-perturbative region (smaller R_L)

When the virtuality approaches $\mathcal{O}(\Lambda_{QCD})$, EEC undergo transition into confinement region

$$\text{virtuality}(\propto p_T R_L) \sim \mathcal{O}(\Lambda_{QCD})$$

$$\rightarrow R_L \sim \mathcal{O}(\Lambda_{QCD})/p_{T,\text{jet}}$$

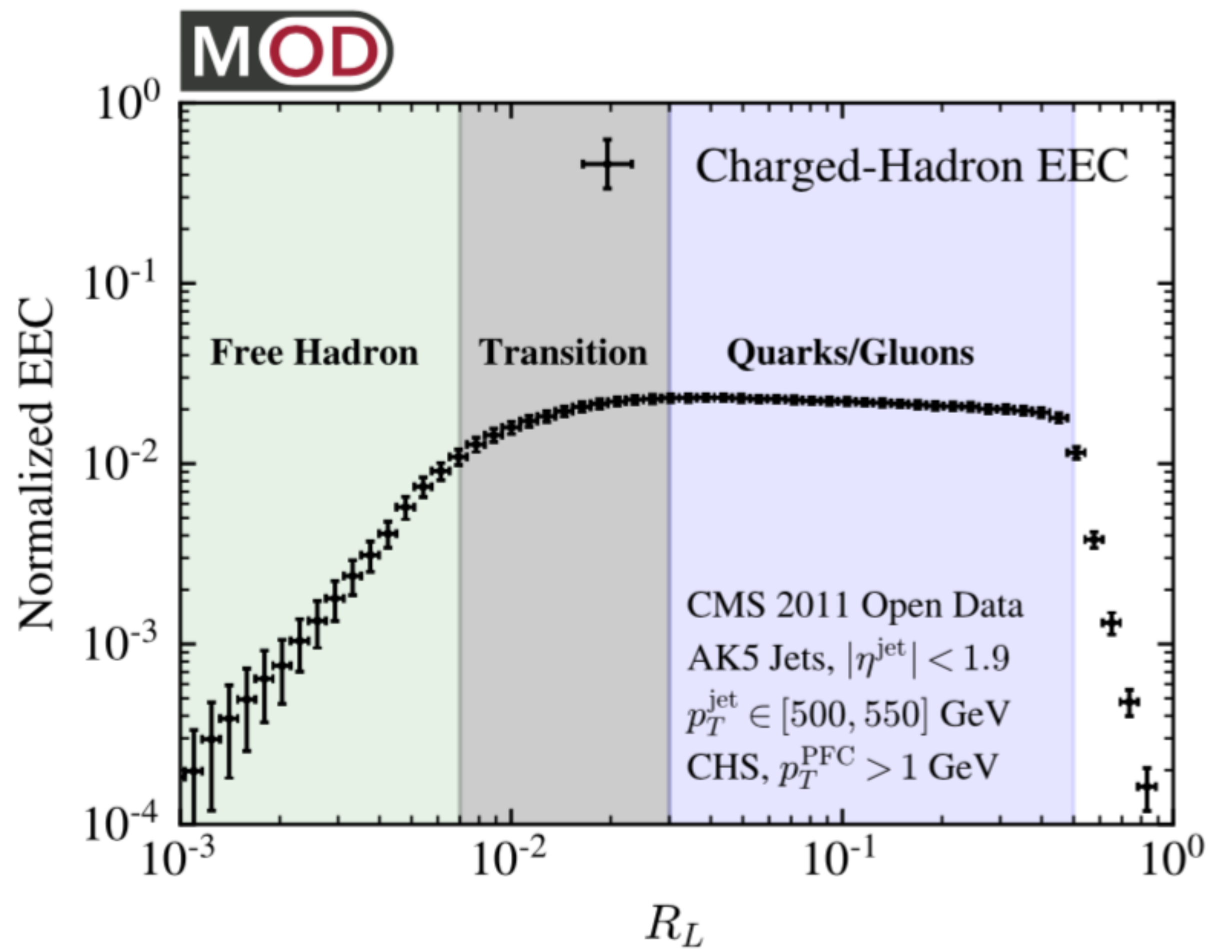


arXiv:2205.03414

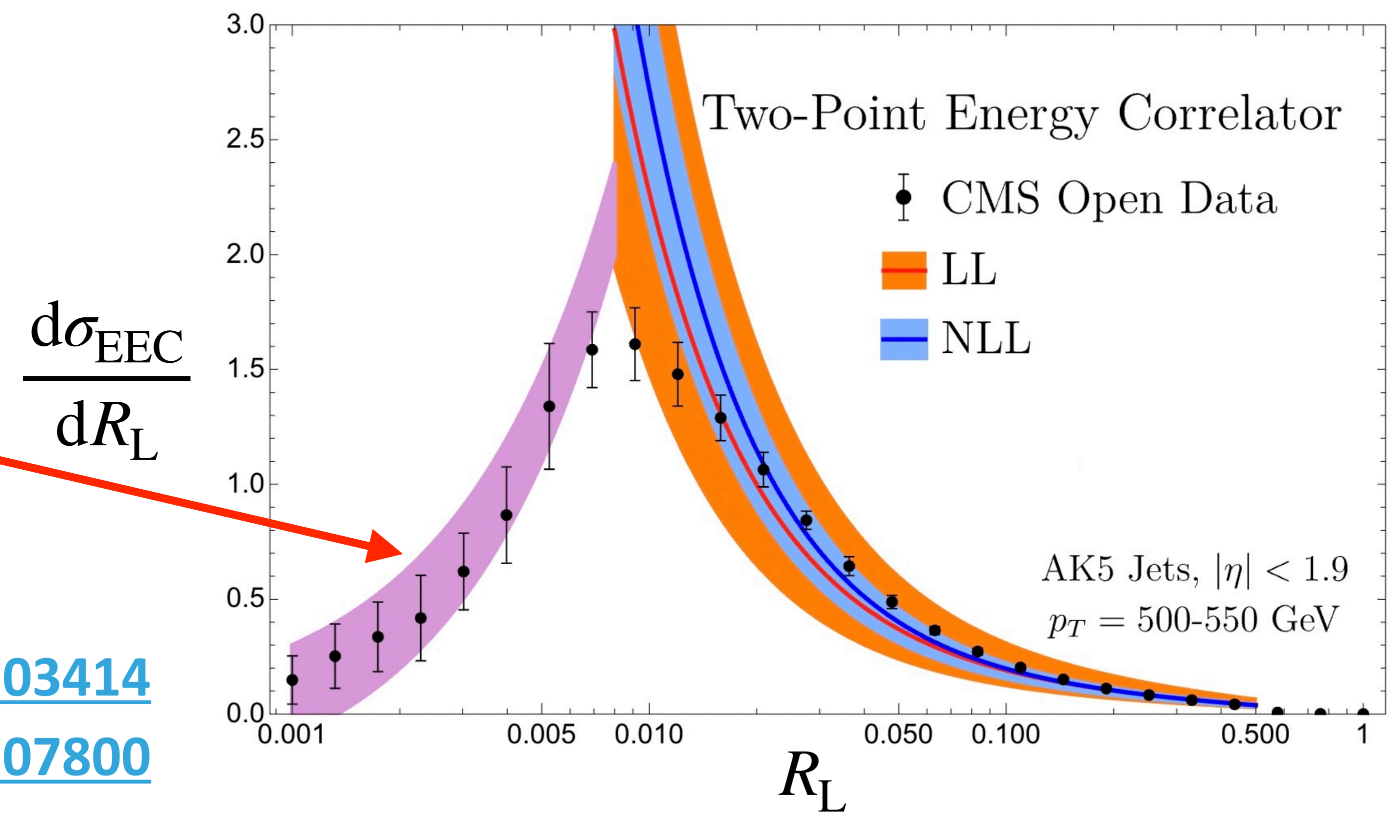
arXiv:2201.07800

Why study this observable in ALICE?

- EEC measurement with ALICE data
  - Good tracking performance: precision measurement
  - Lower jet p_T range: covering perturbative + transition + a broad non-perturbative (NP) region
  - Measure the detector-effects corrected data
  - Study the transition region, the scaling behavior of perturbative and NP region as function of jet p_T



CMS open data results NOT corrected for the detector effects



arXiv:2205.03414
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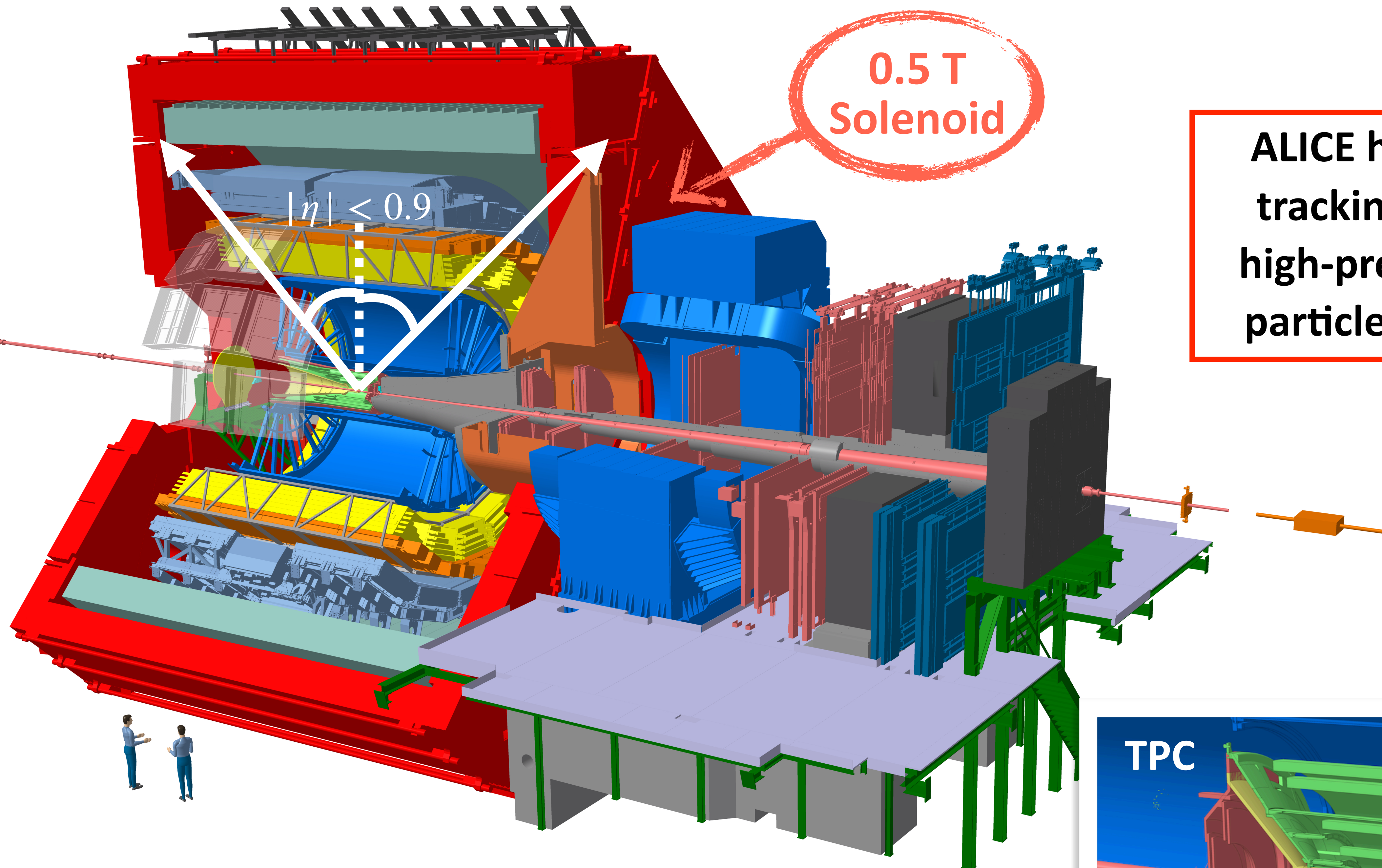
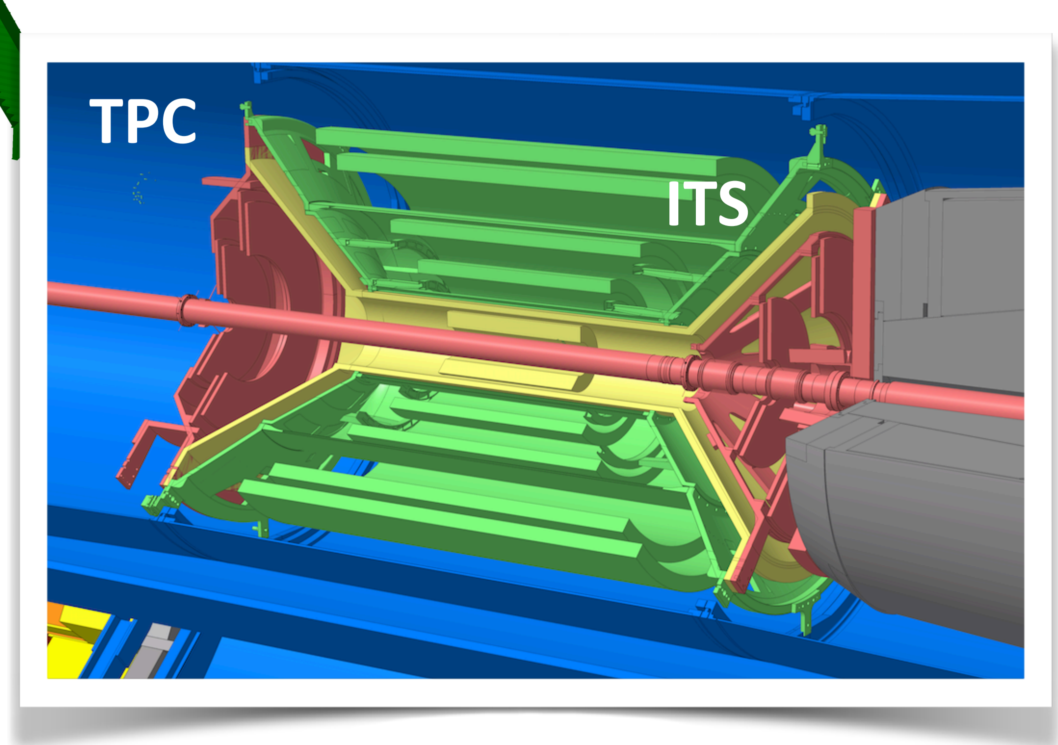
ALICE detector



ALICE high-resolution tracking (ITS+TPC) ➜ high-precision charged particle measurement



Experimental results

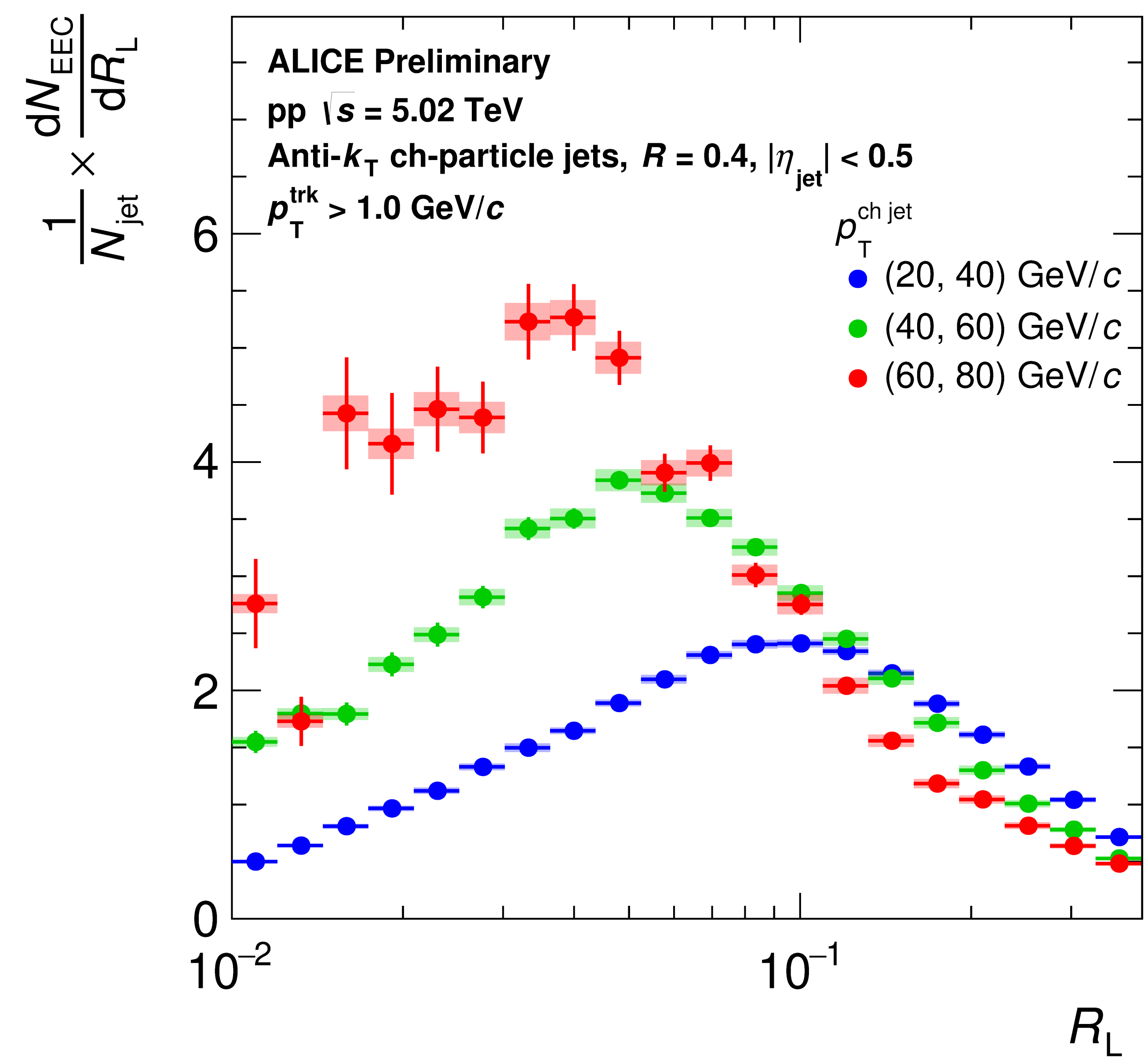
- p+p data measurement
  - p+p 5.02 TeV
  - **R = 0.4 charged jets with p_T in [20,80] GeV/*c* |η|<0.5**
  - p_T threshold for track pairs: p_T > 1.0 GeV (reduce the soft background contributions)
- Detector effects corrected bin-by-bin
  - Data and MC (PYTHIA 8 & Herwig 7) agree at detector level
  - Correction factor is small
  - Small systematics (< 4%)

A clear separation of perturbative and non-perturbative regime

Transition region shift to lower R_L for higher jet p_T range

$$\frac{d\sigma_{\mathrm{EEC}}}{dR_L} = \sum_{i,j} \int d\sigma(R'_L) \frac{p_{T,i}\, p_{T,j}}{p^2_{T,\mathrm{jet}}} \delta(R'_L - R_{L,ij})$$

$$R_L = \sqrt{\Delta\varphi_{ij}^2 + \Delta\eta_{ij}^2}$$

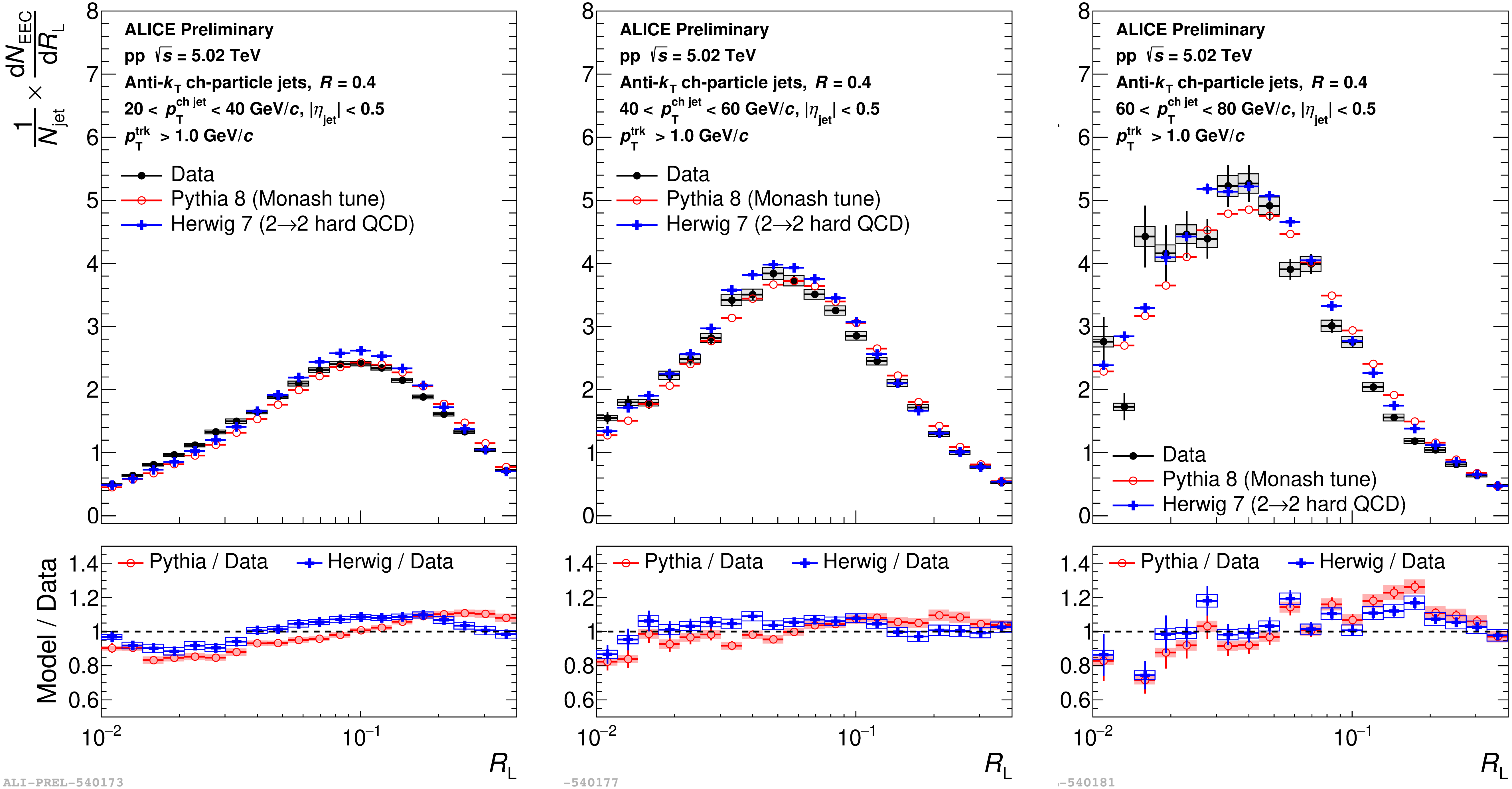


ALI-PREL-540213

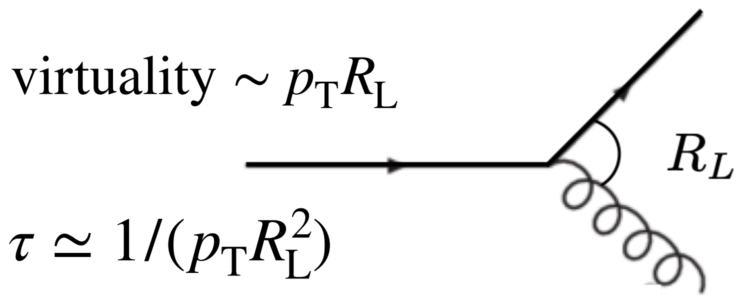
Model comparison

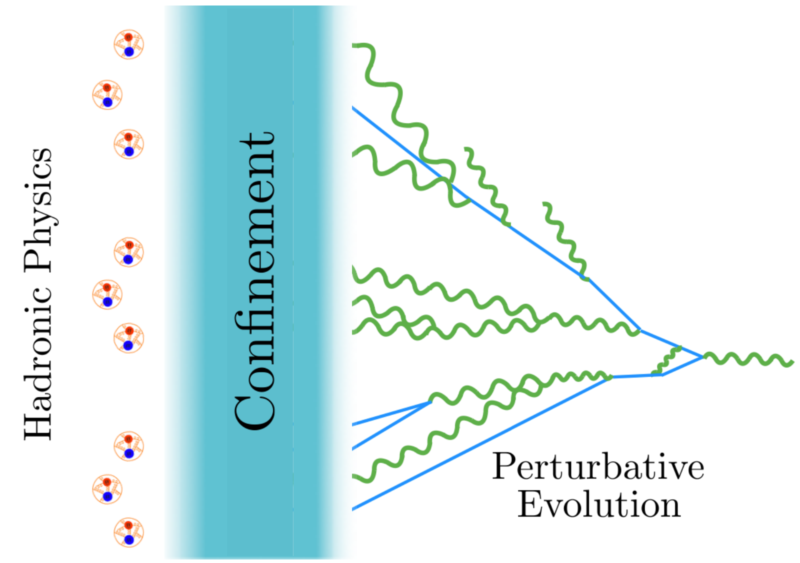
Herwig 7 describes data slightly better than PYTHIA 8

Data has broader width than Herwig 7



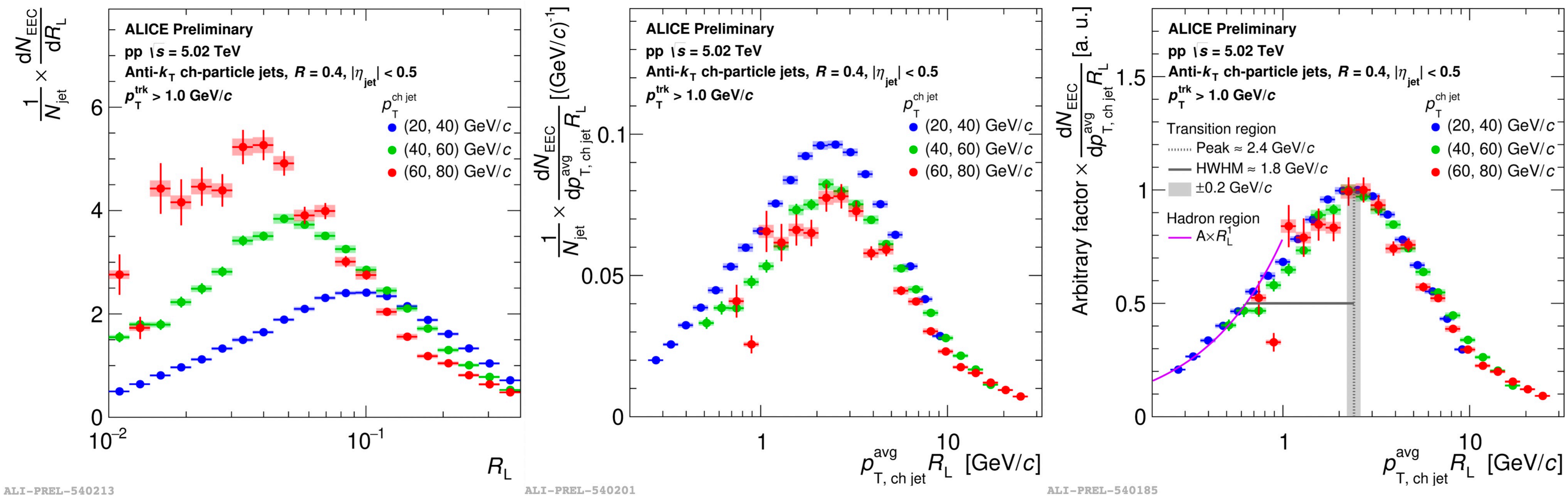
Universal behavior of the transition region





EEC distributions in different jet p_T bin have similar shape

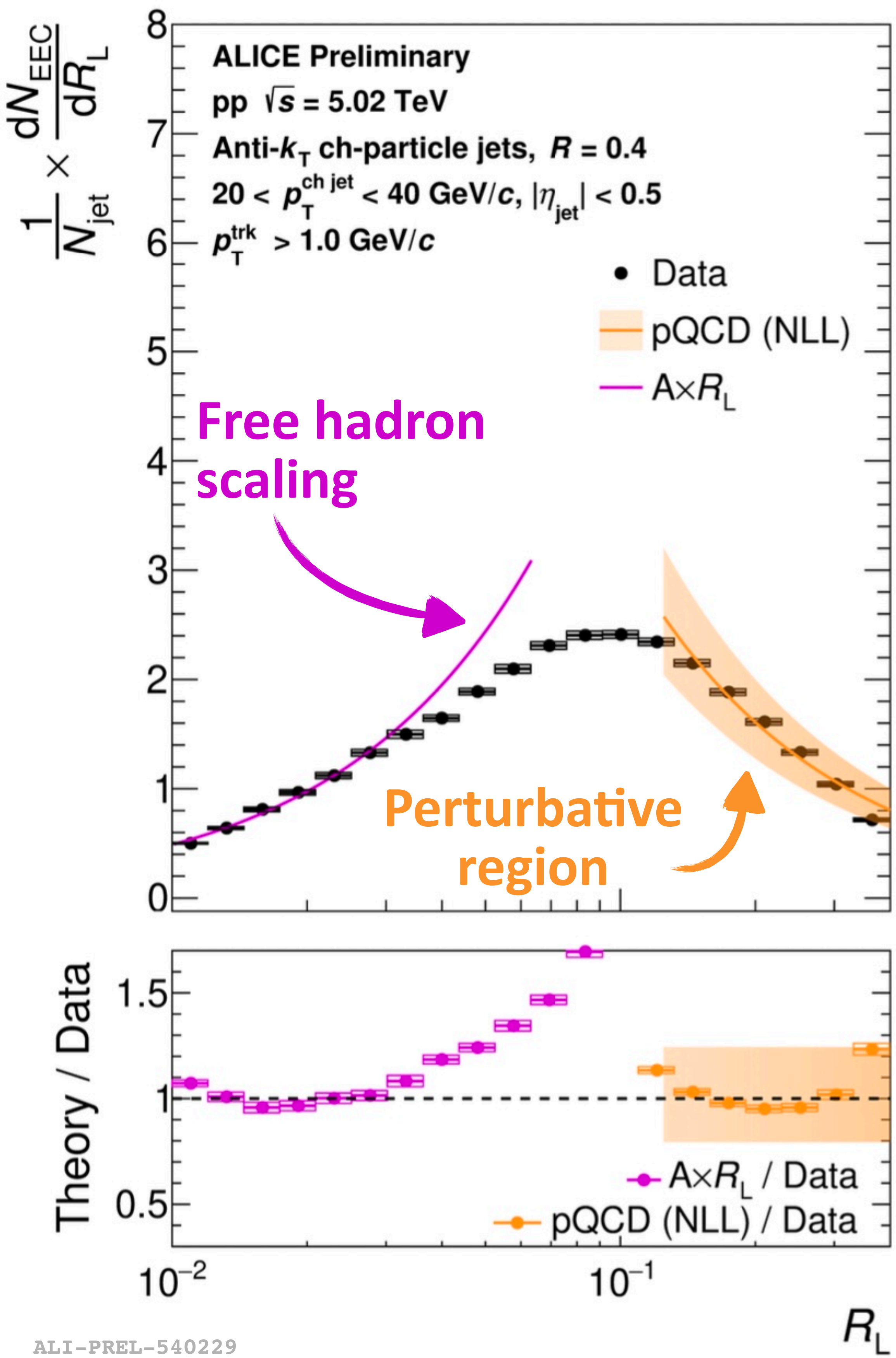
Transition peak position ~2.4 GeV



Scaling angle R_L by jet p_T

Normalizing curves

Comparison with pQCD



From large to small R_L

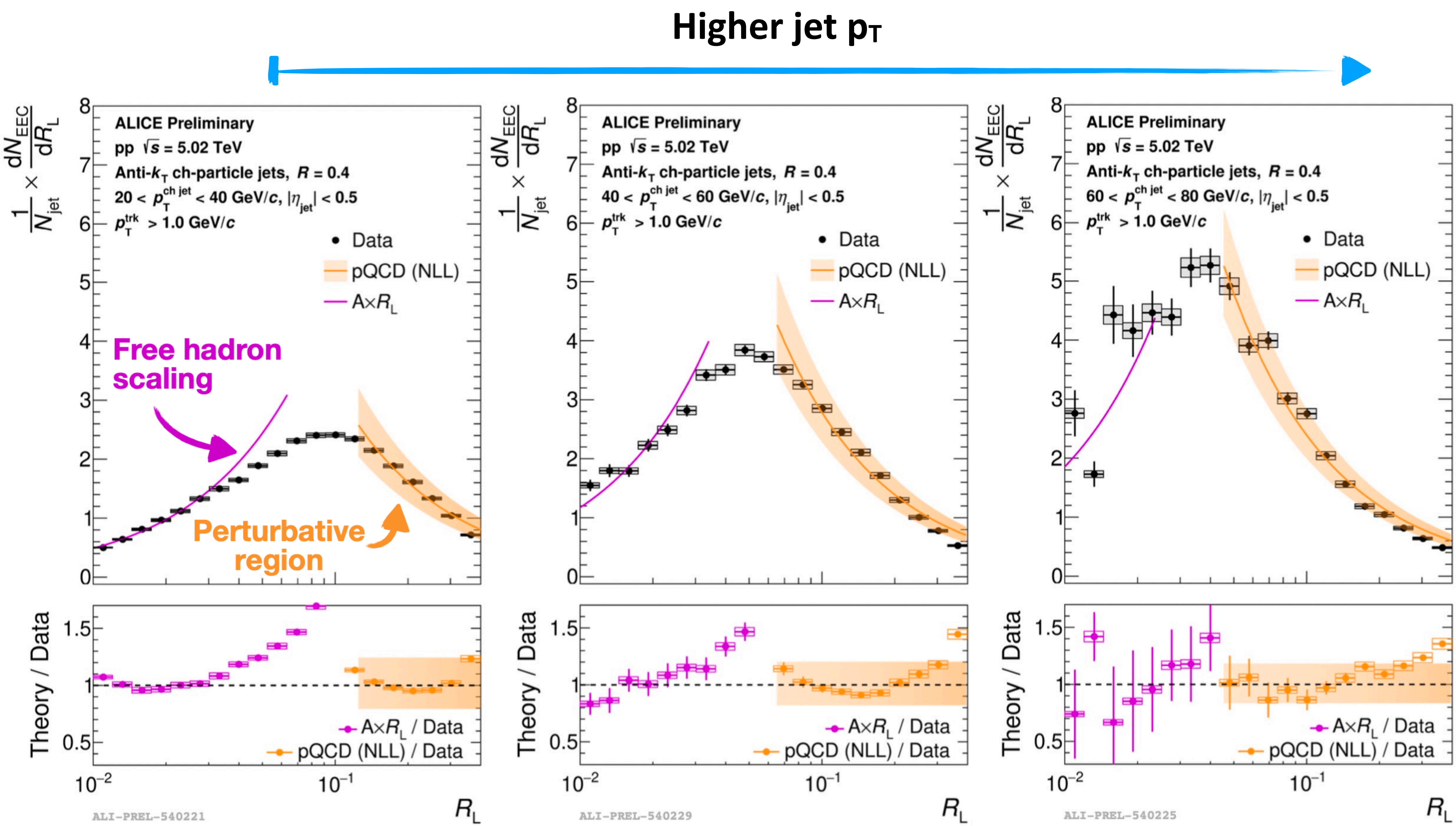
Agreement between data and NLL calculations in the perturbative region

Deviation between data and NLL calculations near transition region: onset of non-perturbative effects

Agreement between data and free hadron scaling: onset of uniformly distributed hadron scaling behavior

NLL calculations correspond to full (charged+neutral) jets and are normalized to data in perturbative region (arXiv:2205.03414)

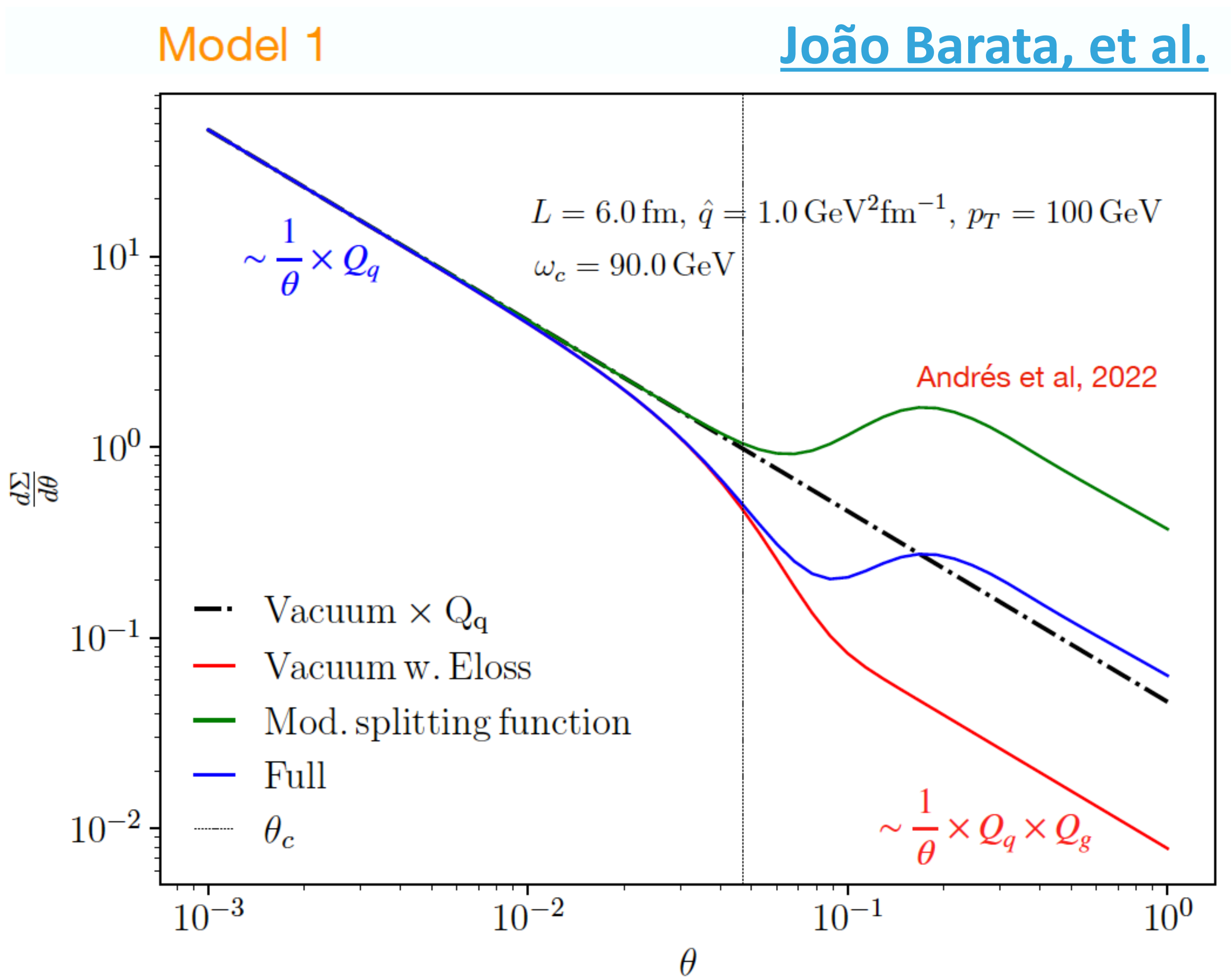
Comparison with pQCD

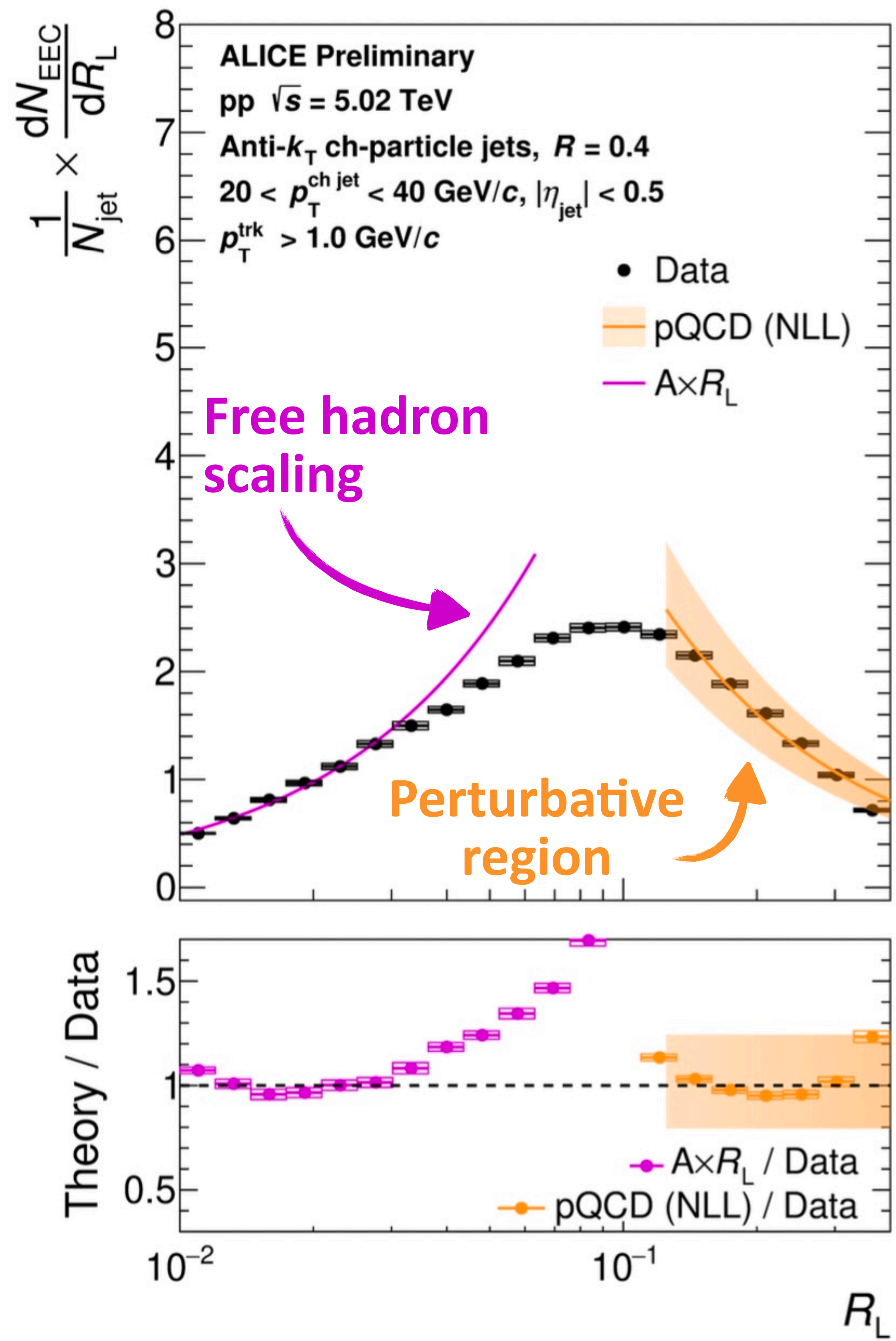


NLL calculations correspond to full (charged+neutral) jets and are normalized to data in perturbative region (arXiv:2205.03414)

Summary and outlook

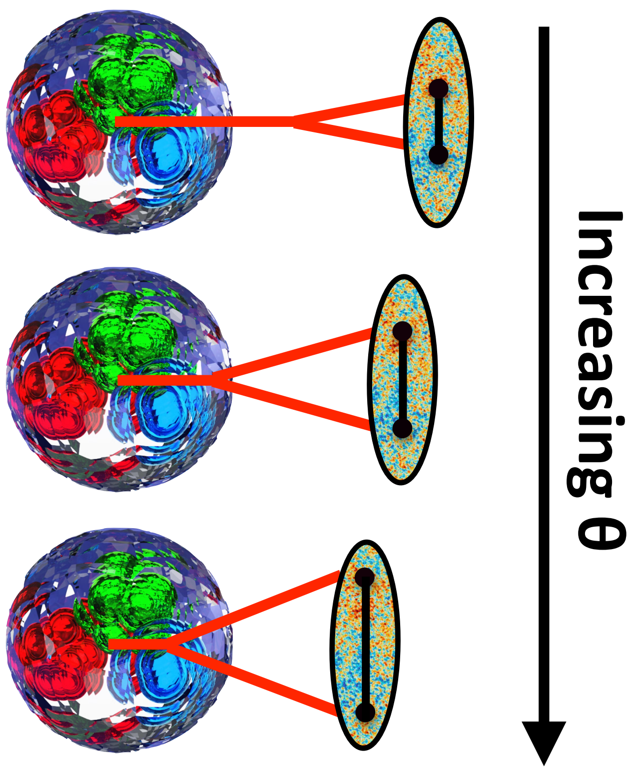
- First fully-corrected EEC measurement at LHC
- Clear separation between hadronic, partonic, and transition (hadronization) regions
- Heavy flavor jet, p-Pb and Pb-Pb analyses ongoing. Stay tuned!



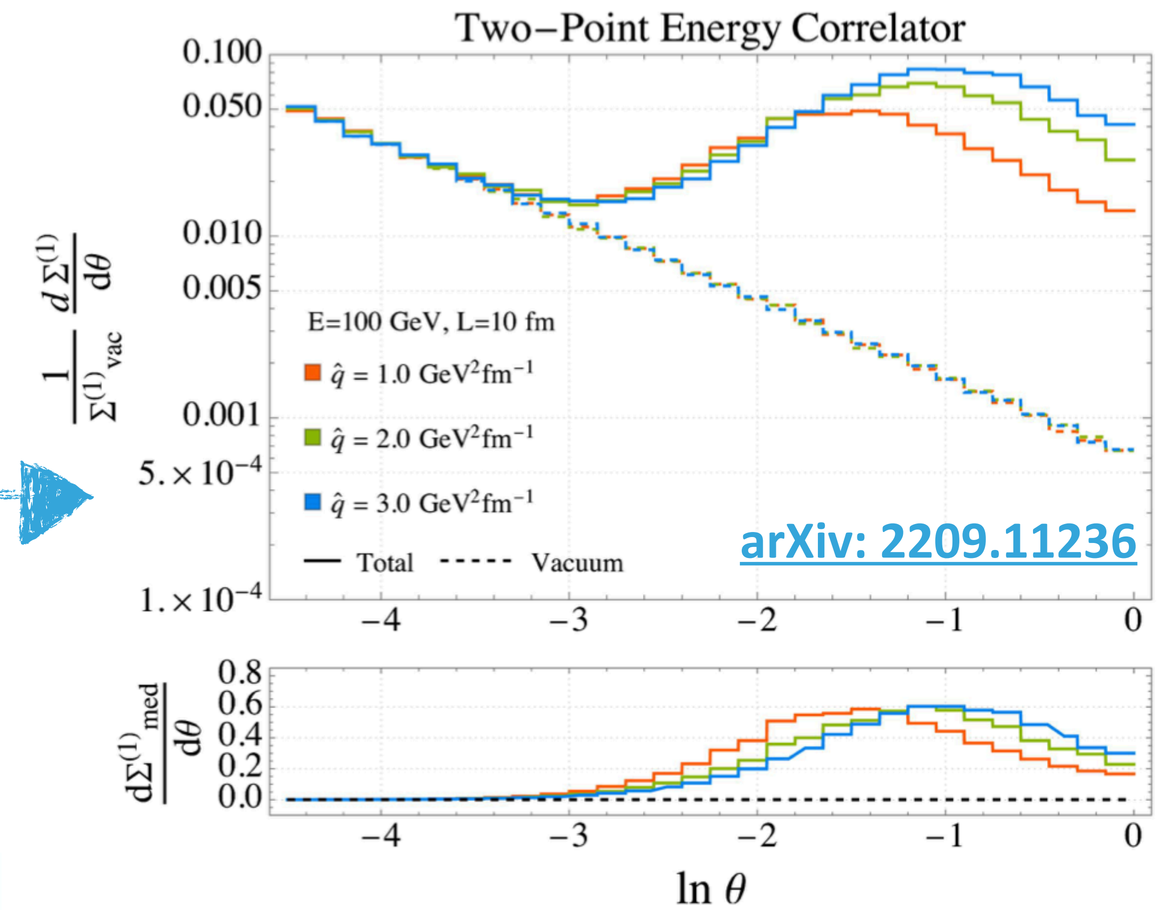


Thanks! + Questions?

Probing QGP with energy correlators



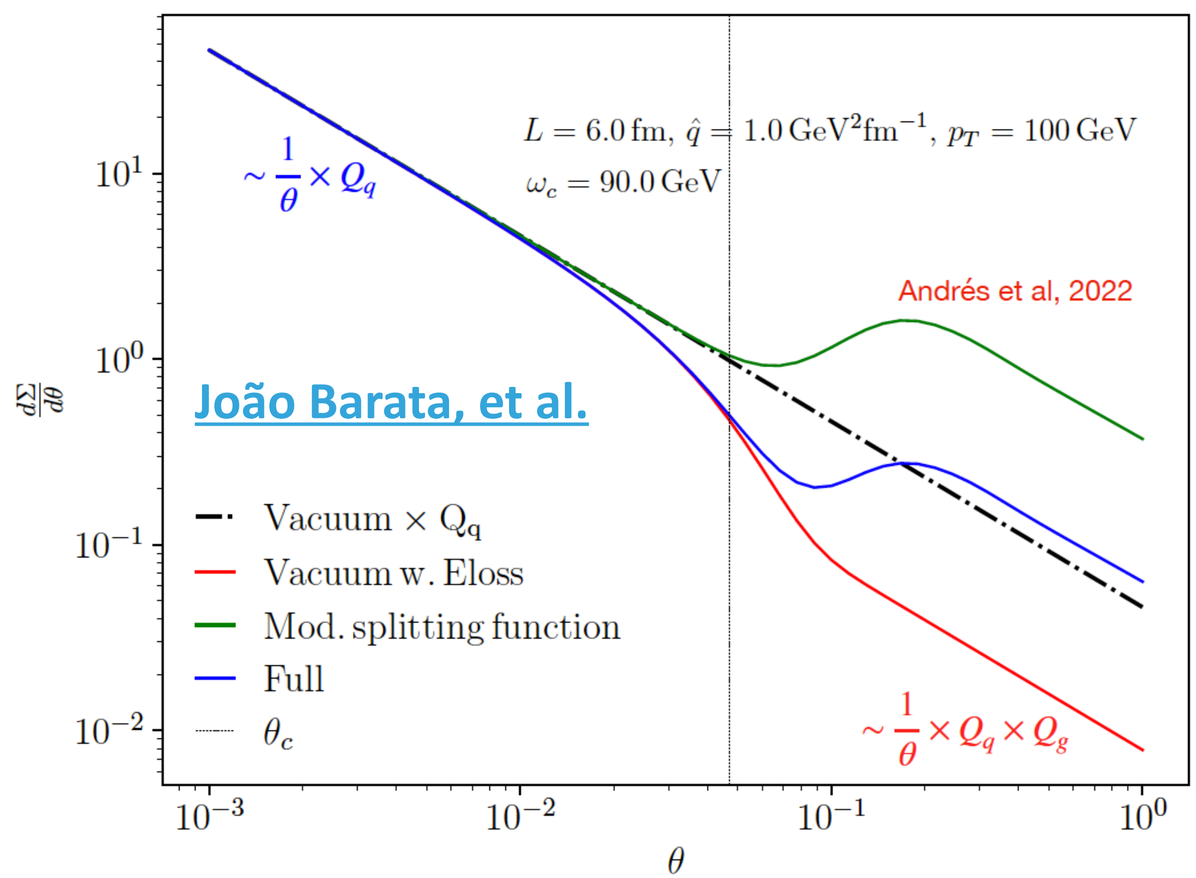
Onset of modification sensitive to medium size



- In the perturbative region:
  - Induced splitting when parton shower in the medium ➜ enhancement at large angle
  - Energy loss of the hard splitting ➜ suppression at large angle
- In the NP region: modified hadronization?

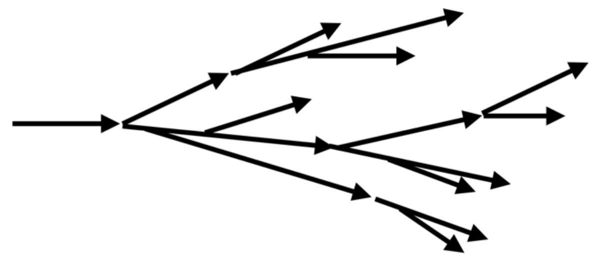
PbPb data analysis ongoing!

Similar studies carried out in eA collisions at EIC (see Kyle Devereaux's talk)

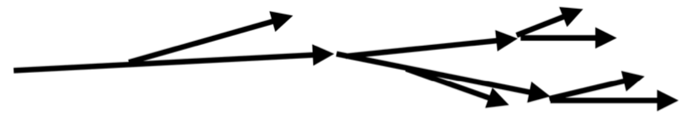


Probing flavor and mass effects

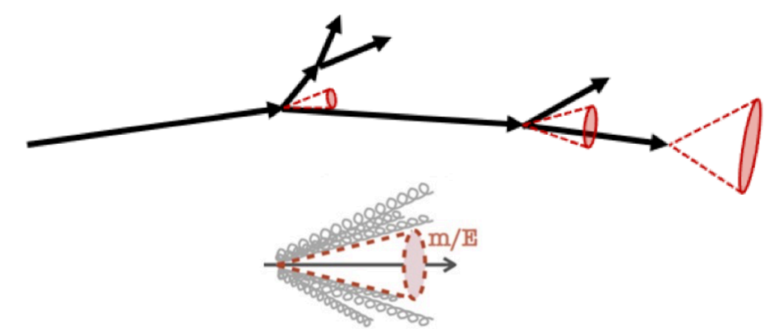
Gluon-initiated shower



Quark-initiated shower

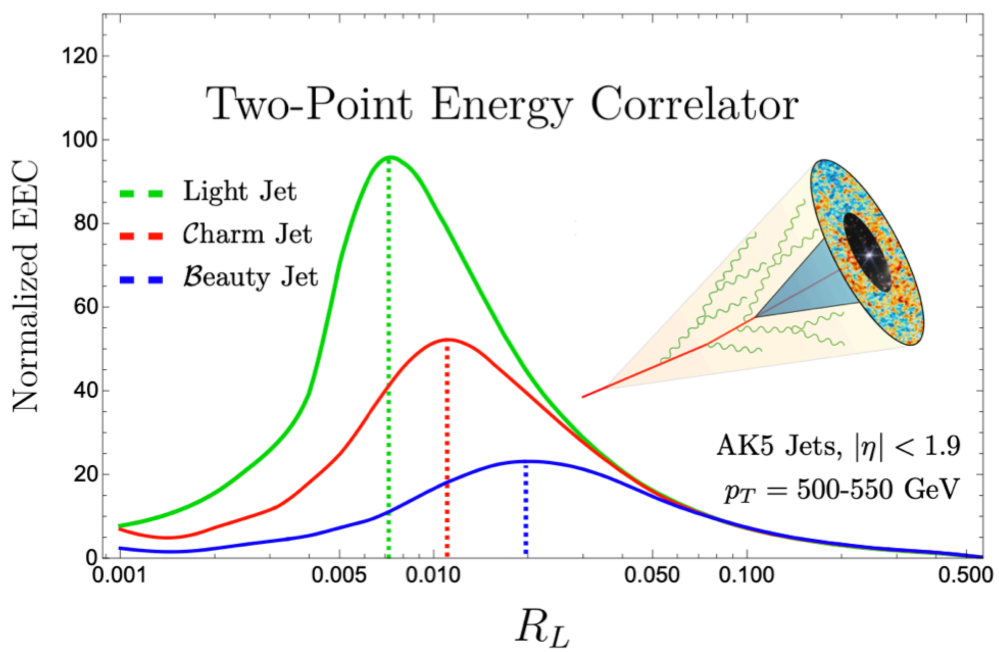


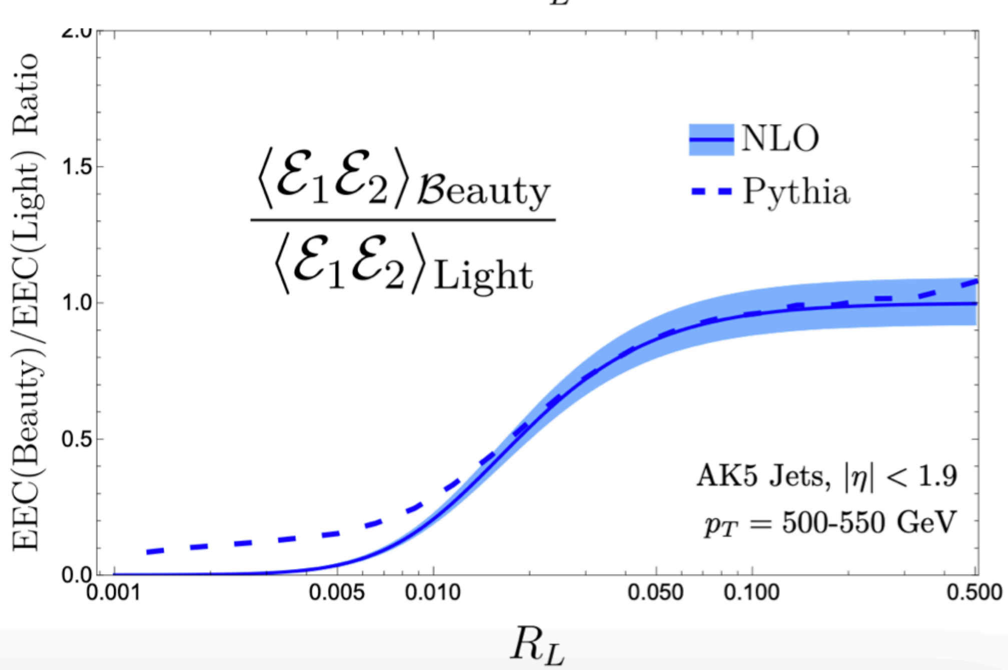
Heavy-quark-initiated shower



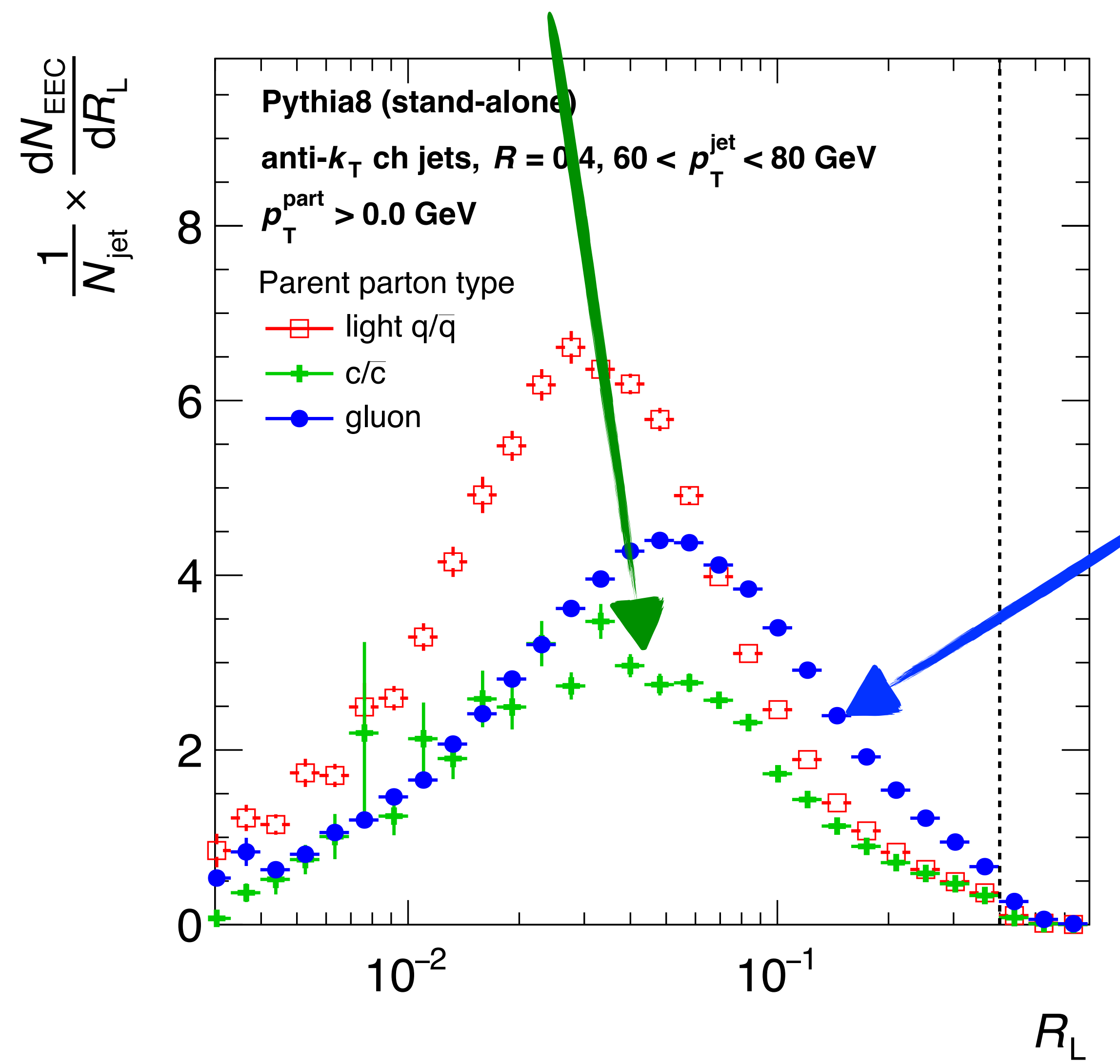
$$\frac{C_A}{C_F} = \frac{9}{4}$$

arXiV: 2210.09311





Suppression of small angle radiation due to dead-cone



Wider fragmentation for gluon jets due to color factor

Using EEC to study QGP

arXiv: 2303.03413